National Needs Drivers for Nanotechnology

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Abstract

Nanoscience and nanotechnology may turn out to have significant societal implications, as would be the case for any truly revolutionary advance in technology. We have identified three areas—natural resources, human condition, and security—where trends are raising significant social issues that will become drivers for technological change. To achieve a safe, secure world we must consider both global and national aspects of security, and the above issue areas are significant in this broader context. These problems are complex and require a life cycle systems approach for technological advances to contribute to real societal solutions. Finally, as with any radically new technology, the consequences of using nanotechnologies can harm as well as help mankind. It is up to society to debate and develop total and durable solutions.

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Introduction

The Clinton Administration's National Nanotechnology Initiative was instituted to

> …support long-term nanoscale research and development leading to potential breakthroughs in areas such as materials and manufacturing, nanoelectronics, medicine and healthcare, environment, energy, chemicals, biotechnology, agriculture, information technology, and national security. The effect of nanotechnology on the health, wealth, and lives of people could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers developed in this century.[1]

We argue that a government research and development initiative of this scale should go one step farther: the breakthroughs sought should relate to the central emerging problems of our society. While curiosity and unforeseen discoveries will still motivate the science, the scientific effort should point in the general direction of contributing elements to systems solutions to the complex challenges that face our nation. We need to think at an early stage about how nanotechnology will affect "the health, wealth, and lives of people."

Coming from a national security laboratory, we tend to think of most of the potential nanotechnology applications as having national security implications. Figure 1 suggests that national security cannot be independent of global security. But global security encompasses many more dimensions than just the military. The consequences of economic and informational globalization, combined with emerging demographic changes, will bring new kinds of threats to national and international security. Individual national security in a world of global collapse will not be tenable. We will have to seek national security in a context of global security (upper left quadrant of Figure 1).

At our nuclear weapons laboratory, we tend to think of problems in terms of systems and life cycles. (Sandia has responsibility for the non-nuclear systems in nuclear weapons from concept to production, to maintenance, and finally to dismantlement.) An example of a technology area where we as a nation did not work the entire life cycle problem is that of nuclear power. By not solving the nuclear waste disposal problem adequately as we developed the power generating systems, we left ourselves with a sizeable unresolved societal problem.

Our analysis of the conditions for global and national security leads us to consider three broad issues. The first revolves around the condition of the planet and its natural resources. We'll refer to this as the "green" issue involving foremost water, energy, and the environment. The second broad issue, which we call "red," is that of the human condition, with health at its center. These first two areas are potential sources of conflict that can drive global insecurity if unresolved. If it fulfills its promise, nanotechnology can

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[1] National Science and Technology Council, Committee on Technology, Subcommittee on Nanoscale Science, Engineering and Technology, *National Nanotechnology Initiative: The Initiative and its Implementation Plan* (Washington, DC: Office of Science and Technology Policy, July, 2000)

enable solutions to many problems within these "red" and "green issues areas. The third issue—which we call "black"—is military, for example as in the area of bio-warfare. Military advances enabled by nanotechnology, if used wisely in the interests of global security, can help to maintain a just peace. If used for purposes of aggression and domination, they can pose a substantial risk to all.

Natural Resources

There appears to be an increased potential for conflict as a rapidly growing world population tries to sustain itself with limited natural resources.[2] The disparity in wealth between developed and developing nations, in combination with the uneven distribution of natural resources, remains a threat to the stability of states and of the international system. With the advent of modern manufacturing, advanced technologies, and the information age, the importance of natural resources has been reduced for developed nations. But, especially for developing nations, the availability and control of critical resources such as oil, water, and food on an increasingly crowded planet remain among the major sources of long-term insecurity. It is possible that nanotechnology will contribute to easing resource disparities. Potential areas of impact include new materials, potable water, new energy sources, and sustainable environmental processes.

The availability of water resources remains one of the big issues for potential insecurity around the globe. As the World Commission on Water for the 21st Century has pointed out,

> What is obvious is that progress, especially in developing countries, is much too slow, and that unless there are drastic changes, water shortages and environmental degradation will become the norm. More people than ever will be added to some of the areas of the planet that are already most vulnerable socially, economically, and environmentally.[3]

Low cost techniques for water purification, self-cleaning, evaporation reduction, and desalination could have tremendous impact by providing adequate supplies of clean water. A major driver for regional conflict might be removed. Adequate water supplies are necessary not only for human health, but also to assure the availability of food for the developing world's growing population. The potential impact of nanotechnology on water supplies is hard to predict at this time, but several areas of significant opportunity come to mind. Affordable, engineered membranes that incorporated a self-cleaning process to avoid fouling could be used for large-scale desalination, which would go far in solving the water resource problem. While this technology would be a significant leap from current capabilities, the ability to tailor nanoscale membranes in combination with

[2] See Brian Nichiporuk, "The Security Dynamics of Demographic Factors", RAND Corporation, MR-1088-WFHF/RF/DLPF/A, 2000; and Lester R. Brown, Christopher Flavin, and Hillary French, *State of the World 2000*, (Washington: Worldwatch Institute, 2000); see also www.worldwatch.org.

[3] *A Water Secure World: Vision for Water, Life, and the Environment* (World Water Council: Paris, 2000), see
http://www.watervision.org/clients/wv/water.nsf/WebAdmin/wUnderConstruction/$file/CommissionReport.pdf

advances in self-assembly processes make it one to watch. In a variation on this concept, the ability to create membranes with molecular receptors that preferentially extract heavy metals and other pollutants is making progress in Department of Energy and other research laboratories.[4] Another potential means of preserving water resources, particularly for agriculture, may be the control of evaporation through large-scale application of nano-engineered films or membranes. Management of water resources is a good example of where the life cycle systems approach should be taken to assure the that the technologies employed do not leave unanticipated environmental problems in their wake.

A second "green" issue of growing long-term concern for global security is that of energy resources and their use. Although proven reserves of oil and natural gas are large, Heavy energy usage by the developed countries, combined with the demographic and development trends of the third world, will eventually put pressure on the supplies. (With less than 5% of the world's population, the United States accounts for about 25% of world energy consumption.) In the meantime, the burning of fossil fuels has at least the possibility of substantially degrading the global environment.

Nanotechnology may be able to ameliorate energy problems both on the supply side and on the use side. In the near term, new, high-strength nanostructured magnets, nanolubricants, and other improved materials may greatly improve motor efficiency. In the long term, nanoengineered fuel cells, biocatalysts for crops for food or biomass fuels, or nanostructured photovoltaic films may permit cheaper alternative energy sources. For example, if the efficiency of photovoltaics were improved by a factor of two from the 20 to the 40% range at comparable costs—something that is theoretically possible—the role of solar energy would grow substantially. Likewise, if the oceans could be used for growing biomass fuels or harvesting energy through nano-biotechnology advances, significant increases in global energy supplies would result.

Systems life cycle thinking is particularly important in addressing the energy issue because of the coupling of energy and the environment. For example, if artificially engineered plants that produce ready-to-use energy become possible, at an early stage we will have to address issues akin to those now arising from the field of genetically engineered foods. But, properly designed, systems using such technologies as photovoltaics, engineered photosynthesis, factory process heat re-use, or agricultural fuel production could lead to a world of sustainable energy, agriculture, and climate. Such an 'open system biosphere' (see Fig. 2) would clearly have enormous implications for global security.

Nanoscience may also enable new materials and technologies that reduce economic dependence on other kinds of natural resources. The dependence of nations on extraction resources might be altered if common materials could achieve the functions of rarer and more costly materials. We refer to the ability to nanostructure a material for specific desired properties not found in its usual forms as *nano-alchemy*. In essence one

[4] "Nanotechnology Research Directions: IWGN Workshop Report", Interagency Working Group on Nanoscience, Engineering and Technology, WTEC, Loyola College, September, 1999.

is creating a new material by nanostructuring rather than by merely changing the chemistry. For example, common materials in the form of nanoscale clusters have been demonstrated to take on specific chemical catalytic properties, superior to those of more expensive catalysts. At this point we cannot predict whether nano-alchemy will apply broadly, or at what cost, but it is possible to envision large changes in how industries work. Then the relative wealth and power of nations could change, as could some of the contributing sources of international conflict.

Note, however, that there are no guarantees that the unregulated marketplace will assure a distribution of the benefits of nanotechnology that brings widespread prosperity and tranquillity. It is also possible to imagine the new technologies being used in ways that help the rich get richer and the poor get poorer. Given that nanoscience is being funded on a large scale from public resources, it behooves us to think on a national level about how its fruits can be directed to enhance national and international prosperity and security

Human Condition

The human condition—the “red” issue—also must be considered in an analysis of the potential societal implications of nanotechnology. In the United States the proportion of the population at retirement age is increasing and will continue to grow rapidly over the next several decades, with a corresponding decrease in the available fraction of workers in the society. This trend has been strong in the developed countries where the birth rate has declined significantly, leading to low or even negative population growth, while life expectancy has been increasing. With an aging population, an increasingly large fraction of national and personal resources is being spent on health care. Here, we will not discuss the additional, very serious health issues, such as AIDS and other emerging infectious diseases that burden developing countries. We would note, however, that if the applications discussed above of nanotechnology to securing clean water were to prove out, they could help with the disease problems of developing countries by improving sanitary conditions.

Desirable goals for an aging population include maintaining productivity longer, providing affordable health care, and deploying assistive technologies that maintain independence longer. Achieving these goals would greatly reduce the burden that an unhealthy, dependent older generation would place on younger citizens. The economic and social benefits to the nation would be great. We consider here just two possible connections to nanoscience and nanotechnology: assistive means to maintain physical independence and tools to support cognitive capability.

In the area of assistive devices, the ability to see (eye repair or hardware to replicate the eye function) and to maintain mobility (prostheses and sensor-based systems) could contribute significantly to maintaining productivity and physical independence. Advances in micro and nanotechnologies hold promise for contributing to a wide range of assistive solutions, from prosthetic limbs that adjust to the changes in the body, to more biocompatible implants, to artificial retinas or ears. Other opportunities lie in the area of neural prosthesis and the 'spinal patch', a device envisioned to repair damage from spinal injuries.

In the area of cognition, revolutionary technical advances could have great impact on individual productivity and independence. We do not understand the workings of the brain well enough to predict with any confidence that assistive devices will actually work. However, rapid advances in the intersecting nano-, information science, and biological sciences seem to promise significant surprises. Possible results include devices that enhance learning, cognition, judgement and decision making. Devices that helped people with dementia—nearly a third of the population over 85—could have great impact. At the same time concerns about the use of artificial or assisted cognition for social control must be addressed.

As with the potential benefits of technologies relating to natural resource use, those relating to human health and quality of life also could end up being available only to small segments of the world's population. Today we talk of the "digital divide"; tomorrow it may be the "nano divide." Only the right combinations of public policy (from whence a significant part of the initial investment in nanoscience is coming) and free enterprise will lead to maximizing the societal benefits of the new technologies.

Security

There is little doubt that nanoscience and nanotechnology will carry implications for the use of force for military and civilian security. Military and police organizations would highly value enhanced situational awareness in a world of ambiguity, confusion, and asymmetric threats. The implications of advances in computing speed, higher density memories, enhanced sensing and communication, and microsystems that, individually or in swarms, may contribute to situational awareness and control are obvious. Nanoscience will enhance all of these technologies. Implications of such advances range from distributed early warning, assessment, and response systems, to enhanced decision support systems. New non-lethal weapons may also emerge.

One area in which our understanding is rapidly growing is that of the emergent behavior of collective systems (see Fig. 3). For example, researchers are beginning to appreciate how bees, with limited individual capabilities and simple rules of interaction, are collectively able to complete complex tasks, such as finding and harvesting nectar. Nanoscience, understanding of cognition, and microtechnologies may combine to give us small, smart devices that sense, think, act, and communicate as swarms. Robotic swarms might play important roles in both security situations and natural disasters where direct human presence would be dangerous or ineffective.

New information technology (possibly nanotech enabled) combined with better understanding of human and machine cognition, may give us new decision support systems. Information display and data fusion are already important military technologies. If memory aids (information storage and analysis) can be integrated with the human brain for decision support, applications in areas beyond military and emergency situations may become available. Related technologies would be interface devices such as wireless communication to the ear or displays on the retina, or reasoning support systems that would serve as decision advisors.

These various advances could contribute to global stability by enhancing the capabilities of peacekeepers to operate in difficult circumstances or of soldiers to resist aggression. As with other enhancements of military capability, however, they could also contribute to the success of military aggression. If the technologies were cheap and widely available, they could expand threats from terrorist or paramilitary groups.

Disruptive Technologies[5]

"Disruptive technologies" are those which produce new products in new ways. Initially, they may cost more and be less effective than the more mature, "sustaining technologies." But eventually, they become so much cheaper and better as to drive the older technologies out of the market. The technologies emerging from nanoscience may well prove disruptive. If so, they will have societal implications that extend beyond their functional applications and into the realms of industry and economy (see Fig. 4) Particular manufacturing firms, and perhaps entire industries (e.g. petroleum, agriculture) might be deeply changed, or even shrink to insignificance. Some managers and workers might be put out of business, while others may prosper. Those with the resources and adaptability to retrain may succeed, while others--perhaps especially older workers--may not make the transition successfully. Redistributions of economic power could lead to corresponding redistributions of political influence.

The international status of the nations which first master the new technologies may rise, while the nations overly committed to old industrial processes or to extracted resources may fall behind. As on the national level, redistributions of global technological strength could result in realignments of global prosperity and influence. These changes could promote national and international stability and security—or they could hinder it.

Conclusions

Nanoscience and nanotechnology may turn out to have significant societal implications, as would be the case for any truly revolutionary advance in technology (Fig. 4). We have identified three areas—natural resources, human condition, and security where trends are raising significant social issues that will become drivers for technological change. To achieve a safe, secure world we must consider both global and national aspects of security, and the above issue areas are significant in this broader context. These problems are complex and require a life cycle systems approach for technological advances to contribute to real societal solutions. Finally, as with any disruptive technology the advances brought about can be used for good or evil. It is up to society to debate and develop total and durable solutions.

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[5] A term coined by Clayton M. Christensen, *The Innovator's Dilemma : When New Technologies Cause Great Firms to Fail* (New York: Harperbusiness, 2000).

Figures

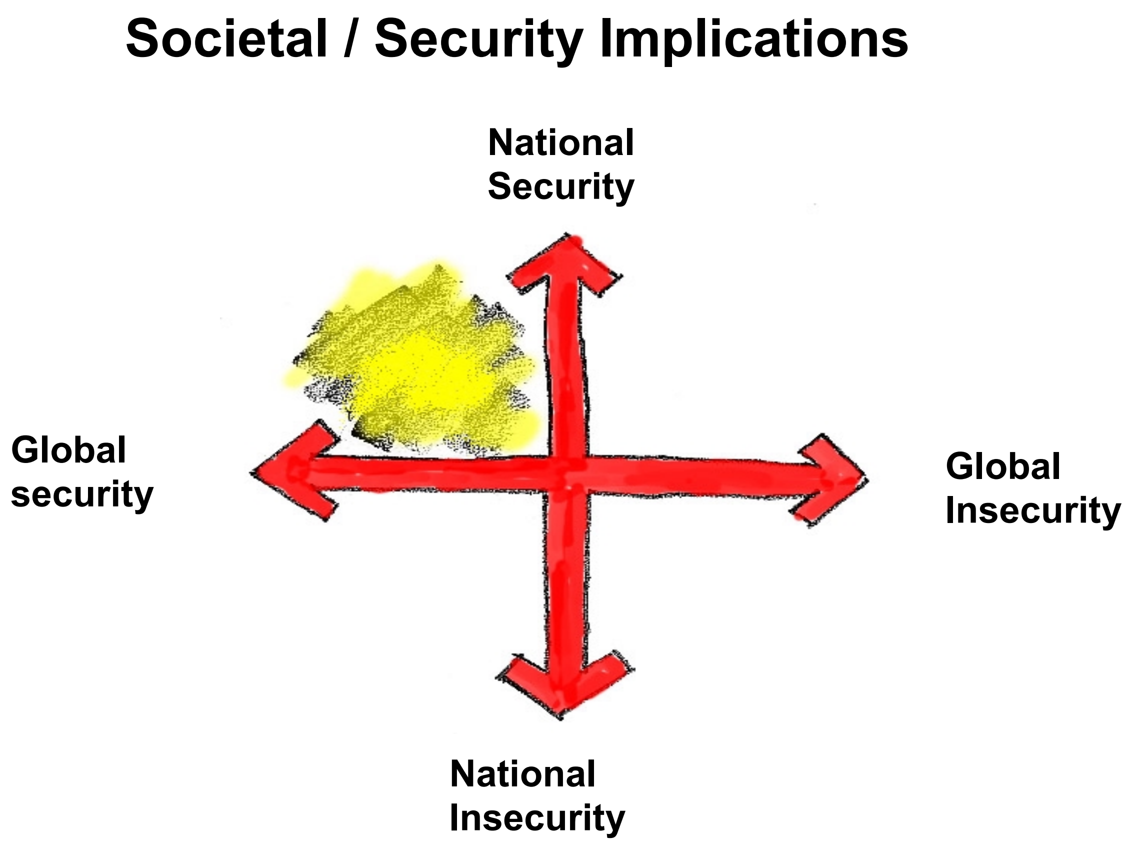

Figure 1: A Secure nation in a secure world

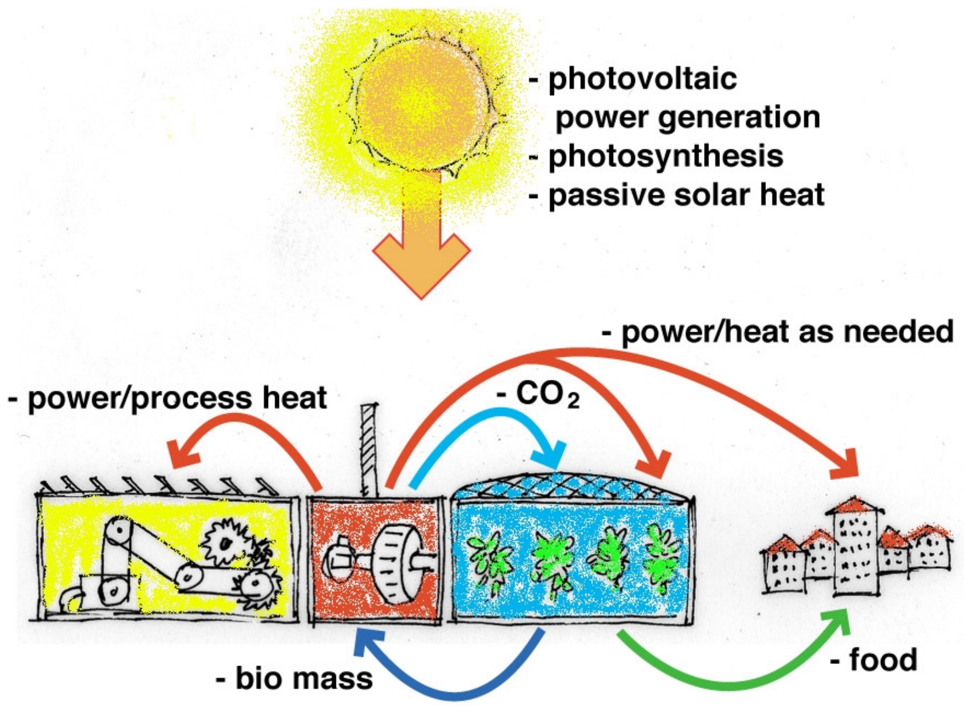

Figure 2: Open System Biosphere—a city model for sustainable energy, agriculture, and climate.

Nano → microdevice → swarm system → collective emergent behavior

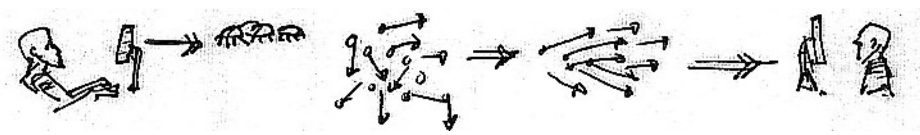

Figure 3: Nanotechnology may be a key enabling element to creating small, smart swarms of devices that sense, think, act, and communicate--resulting in emergent behavior of collective systems.

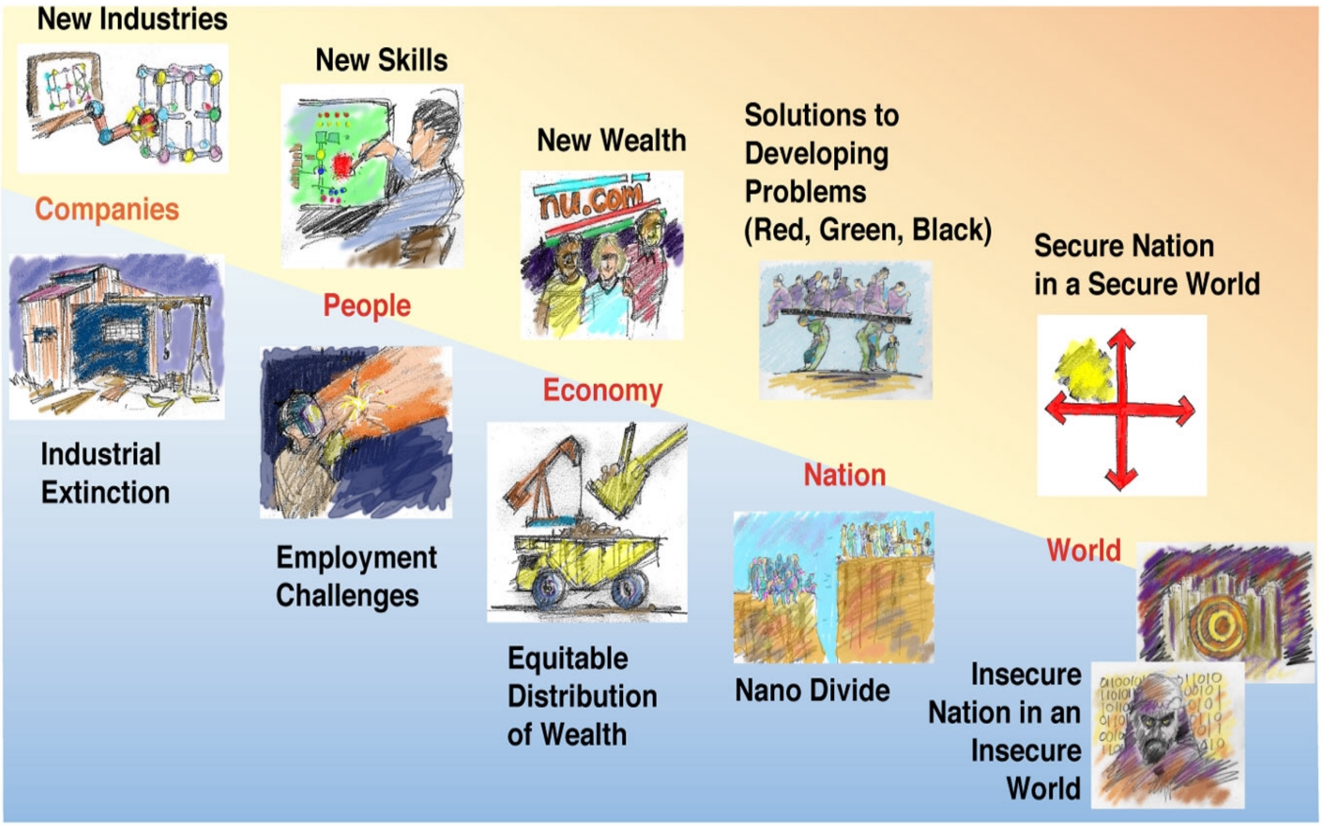

Figure 4. Nanotechnology may fall into the category of disruptive technologies where significant new capabilities and industrial systems bring large-scale changes, which may result in the betterment of society or may create new problems.